Data-Driven Geometrical Measurement and Analysis for Realistic Garment Materials

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Abstract

Garment materials exhibit nonlinear and anisotropic behavior due to their woven patterns and fiber properties. It has become more and more important to judge textiles physical performances before any production process. However, the isolation and measurement of each material parameter would require complicated test environment and equipments. This paper proposes an efficient and expressive data-driven geometrical measurement method to obtain the properties of realistic garment materials. The key idea in this work is to objectively measure the fabric hand attributes. We first developed a direct geometrical material measurement method for testing the recovery, stretching and bending behaviors of different real cloth samples. Our setup is easy and inexpensive to construct, and the measurements allow us to build a database that includes fit parameters which exhibit respective anisotropic behaviors for a range of different materials.

Keywords: Garment material; Geometrical measurement; Anisotropic behavior; Data-driven; Parameter optimization

1. Introduction

Different garment materials exhibit distinctive appearances in draping, folding and wrinkling owing to their properties of woven pattern and fibrous composition. There are two main approaches to achieve real-world cloth material behaviors. Although the device can be used to isolate each material parameter and measures it directly in materials science and textile engineering [1,2], it is often complicated in large and expensive machines, and the large number of parameters prevents such a device to describe the behavior of real cloths. A further complication arises because cross-terms may cause one parameter to depend on phenomena controlled by another. Other works in graphics has instead tried to estimate cloth material parameters from unconstrained motion in images or videos [3,4]. Although their experiments do not require specific devices and can be easily set up, the unconstrained nature of the motions makes it difficult to define meaningful features that can be tracked and used in the optimization process.

This paper proposes a novel method to achieve a balance between the above two approaches. We built simple devices that deform samples in a controlled way so that their shapes can be easily measured. We measured some key geometric features of the garment material in real experiments. An overview of our method is sketched in Fig. 1. The main contributions of this work are as follows:

(1) We proposed a new geometrical method to measure the recovery, stretching and bending behaviors of garment materials.
(2) On the basis of data-driven guidance, we developed a quadratic fitting method to fit parameters in the garment materials from the data measured with real cloth samples.
(3) We built a database that includes both real measurement data and optimized parameters which can model the anisotropic behaviors of different garment materials.

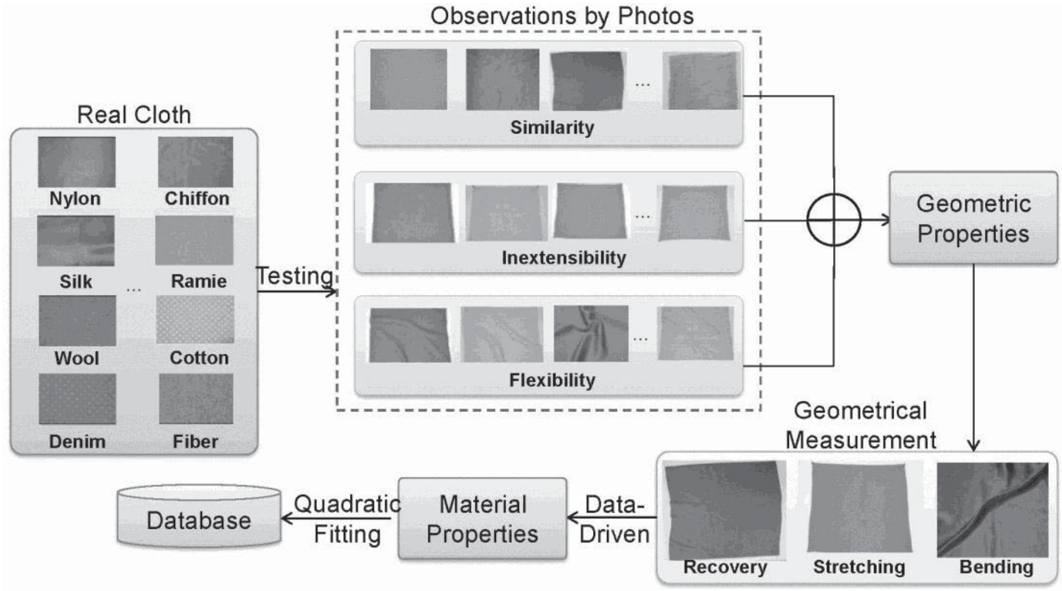


Fig. 1. The overview of our method.

2. Related work

Devices [5] that directly capture stiffness parameters from real cloth samples are used in materials science and textile engineering, including biaxial tensile testers developed by KATO Tech [6] and Zwick [7]. These machines must be carefully designed to isolate the parameters to be measured. It is difficult to avoid interactions among different anisotropic behaviors and the deformations on the sample edges.

Volino and his collaborators [8] proposed an elastic model based on one-dimensional strain-stress curves that were directly measured from unidirectional tensile tests. While their model approximates well elastic behaviors of stiff cloth material, they do not consider the relationship among stiffness parameters in different directions. Therefore, the model is not sufficient to handle compliant materials with obvious Poisson effects. Poisson effects can also affect the accuracy of unidirectional tensile tests. Alternatively, other researchers [3,4] have presented automatic techniques to learn stiffness parameters from unconstrained cloth motions. While their experiments do not need specific devices and can be easily set up, the unconstrained nature of the motions makes it difficult to define meaningful features that can be tracked and used in the optimization process.

Bickel and collaborators [9] proposed a system to capture and model nonlinear heterogeneous soft tissue in three dimensions. Although they only use two parameters for each data point under the locally isotropic assumption, they assign a data point to each tetrahedron in every example measurement, which greatly increases the number of parameters for fitting. Directly capturing and reconstructing cloth animation from videos is also a problem addressed in graphics, including marker-based techniques by White and his collaborators [10] and markerless approaches by Bradley [11].

Our key observation from the real cloths is that we can obtain the geometric properties of realistic garment materials. Our work is also related to the cloth optimization framework proposed by Huamin Wang [12] and Wojtan and his colleagues [13]. While their work is focused on optimizing cloth motion for a mass-spring system, we are interested in finding stiffness parameters for elastic models in continuum-based cloth simulation. This research is inspired by the goal of capturing real cloth behaviors based on the material-aware cloth simulation method by Liu et al. [14]. Distinct from several other approaches, we develop the approach of directly measuring the geometric parameters for different types of cloth samples.

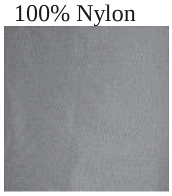
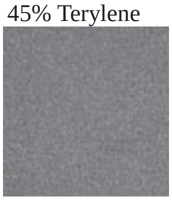
3. Geometrical material measurement

We propose a geometrical material measurement for cloth simulation by directly measuring the geometric parameters of various types of real cloths. The method relies on the three geometrical variances, which are all easy to measure, as reflected by the simple setup of the measurement device. We find optimal parameters that closely match the actual material properties of each cloth.

3.1 Material properties

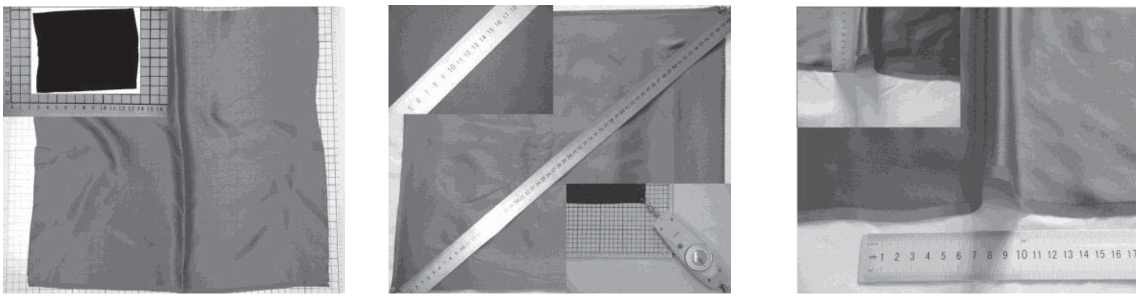
Different materials exhibit different behaviors when the cloth is suspended or wrinkled [15]. Therefore, we select 10 different cloth samples of size 460×400 mm^2 as shown in Table 1. The 10 materials in our experiments have different fabric compositions including silk, jean, cotton, linen, nylon, polyester fiber and wool. These materials are representative of common garment materials encountered in daily life, and they exhibit different woven or knitted patterns and different behaviors. Ten different garment materials exhibit distinctive properties of similarity, extensibility and flexibility.

Table 1. Ten different garment materials

Color & Name	Red silk	Blue white dot canvas	Blue washed star jean	Apricot linen	Color blue nylon
Materials	100% Silk	100% Cotton	100% Cotton	100% Linen	100% Nylon
Sample 0-4					
Common Usage	Chirpaur, skirt	Bag, curtain	Jeans	Dress, curtain	Sports clothes
Color & Name	Green woolen	Blue poplin	Orange ramie	Gray fiber	White satin
Materials	55% Wool 45% Terylene	30% Silk 70% Cotton	55% Cotton 45%Polyester	55% Linen 45% Cotton	95%Polyester 5% Spandex
Sample 5-9					
Common Usage	Overcoat	Shirt	Clothing	Table cloth	Dress

3.2 Geometrical measurement

All of these given garment materials exhibit nonlinear and anisotropic behaviors in the ease of recovery, stretching and bending due to their fiber attributes including resilience, extensibility and flexibility, respectively. Our measurement emphasizes the direct determination of the material properties in direct response to an efficient constrained geometric deformation using a novel geometrically based experimental setup. As shown in Fig. 2, the geometrically measurement were built. These experiments and optimization process allow us to model specific parameters automatically from captured cloth behaviors.



(a) recovery tests (b) stretching tests (c) bending tests

Fig. 2. The geometrically based measurement setup

Recovery test: To capture the property of similarity, we designed a series of experiments to test the variance of the projected area between each initial cloth sample and the deformed sample. We repeated these experiments 10 times by compressing and unfolding each cloth sample, indicating where the material fell on the range from soft to hard. We configured a recovery tester as shown in Fig. 2(a). The first measurement for the computation of projected area is carried out using a Canon EOS 550D made in Japan, an 18.0 megapixel digital single-lens reflex (DSLR) camera with continuous shooting at 3.7 fps and a DIGIC 4 processor. The camera lens was positioned 71.5 cm from cloth samples. The data obtained from the real cloth are shown in Table 2.

Stretching test: In our method, we pull the cloth up along the diagonal with a vertex around the corner by fixing the other three vertices of the flat cloth. Each sample is typically tested with three different weights ranging from 500 g to 900 g with a 01 orientation using a pointer tensiometer, and the diagonal length is gauged with a metric ruler as shown in Fig. 2(b). This experiment enables effective comparison of the variation in stretching between each initial cloth sample and the stretched sample. Table 2 shows the results for the extensibility of each cloth sample.

Bending test: Fig. 2(c) shows the experimental setup for the bending behavior of each cloth sample by recording the height of the bending angle. Unlike other methods for testing bending properties using technical devices and sensors, our experiment is convenient and it directly yields the geometrical results shown in Table 2.

The values for representing the recovery, stretching and bending properties of cloth samples can be obtained by:

$$\begin{cases} p(A_i) = \overline{A_i^j} \big/ A_i^{ini}, \\ p(L_i) = \overline{L_i^j} \big/ L_i^{ini}, \\ p(H_i) = \overline{H_i^j} \big/ H_i^{\max}, \end{cases} \tag{1}$$

where A_i^{ini} is the initial projected area of each cloth sample and $\overline{A_i^j}$ is the average projected area of the deformed cloth sample. L_i^{ini} is the initial diagonal length of each cloth sample and $\overline{L_i^j}$ is the average diagonal length of the entire tested sample. For the bending measurement, $H_i^{\max}$ represents the maximum bending angle height of the wrinkles on each cloth sample and $\overline{H_i^j}$ is the average maximum bending angle height of the tested cloth samples. i and j indicate the numbers of cloth samples and measurements, respectively, with $i \in [0,9]$, $j \in [0,9]$. In total, 10 recovery, 30 stretching and 10 bending tests were conducted for each sample, for a total of 500 tests for all cloth samples.

Table 2. The mean numerical values of $p(A_i)$, $p(L_i)$ and $p(H_i)$ for recovery, stretching, and bending tests

Real fabrics	Material properties			Real fabrics	Material properties		
	$p(A_i)$	$p(L_i)$	$p(H_i)$		$p(A_i)$	$p(L_i)$	$p(H_i)$
0_Red silk	0.9883	1.0209	0.9933	5_Green woolen	0.9848	1.0488	0.999
1_ Blue white dot canvas	0.9755	1.0256	0.9993	6_Blue poplin	0.9883	1.0413	0.994
2_ Blue washed star denim	0.9896	1.1014	0.9968	7_Orange ramie	0.9745	1.1242	0.9984
3-Apricot linen	0.969	1.0337	0.9984	8_Gray fiber	0.9871	1.0613	0.9932
4_Blue nylon	0.9781	1.0218	0.9981	9_White satin	0.9833	1.0507	0.995

3.3 Parameter optimization

Given the above values, we hypothesized that the maximum (minimum) in the test dataset was not greater than (less than) the maximum (minimum) values in the training dataset for each cloth sample. We used the normalization method to map all the data from 0 to 1, mainly due to the inconsistency among units and the inconvenience of data processing. The normalized results of the recovery tests can be obtained by the formula (2).

$$\lambda(A_i) = \frac{p(A_i) - \min p(A_i)}{\max p(A_i) - \min p(A_i)} \quad . \tag{2}$$

Similarly, the normalized results $\lambda(L_i)$ and $\lambda(H_i)$ of the stretching and bending tests for each cloth sample can be achieved. Using the first normalized results, we can capture the correlation between the three parameters $\partial(r), \partial(s), \partial(b)$ for the three geometric variations in terms of projected area, length and height. The model generates fitted configurations that are sufficiently well controlled to model different garment materials. With the further normalization, a correlation can be achieved by quadratically mapping the weights in $[0,1]$ based on the learned values $\lambda(A_i), \lambda(L_i), \lambda(H_i)$ as follows. And the algorithm 1 gives the parameters learned from the real measuring data.

$$\begin{cases} \partial(r) = \lambda(A_i)/(\lambda(A_i) + \lambda(L_i) + \lambda(H_i)), \\ \partial(s) = \lambda(L_i)/(\lambda(S_i) + \lambda(L_i) + \lambda(H_i)), \\ \partial(b) = \lambda(H_i)/(\lambda(S_i) + \lambda(L_i) + \lambda(H_i)). \end{cases} \tag{3}$$

Algorithm 1. The parameter optimization scheme.

Input: A_i^j, L_i^j, H_i^j : the measured data for each cloth sample, i :cloth samples, j : tests
Output: $\partial(r), \partial(s), \partial(b)$: the optimized parameters
Begin
for $i = 0$ to 9 **do** normalize the data
    for $j = 0$ **do** the values based on testing data Eq. (1)
    end for
    do the normalized results of the recovery tests Eq. (2)
end for
for $i = 0$ to 9 **do** the relative ratio between three parameters Eq. (3)
end for
return
End

4. Database

We obtain the relative ratio between the three parameters shown in Table 3. The three parameters $\partial(r), \partial(s), \partial(b)$ are determined from real data on the recovery, stretching and bending resistance of each cloth sample shown in Table 1. For example, the relative ratio $\partial(s)$ of silk and nylon indicate that these materials are more extensible than other materials. Apricot linen has less resilience than other materials, and gray fiber has less bending resistance. In addition, based on the analysis of the data in Table 2, we would like to discuss a specific type of material with a specific configuration of these parameters.

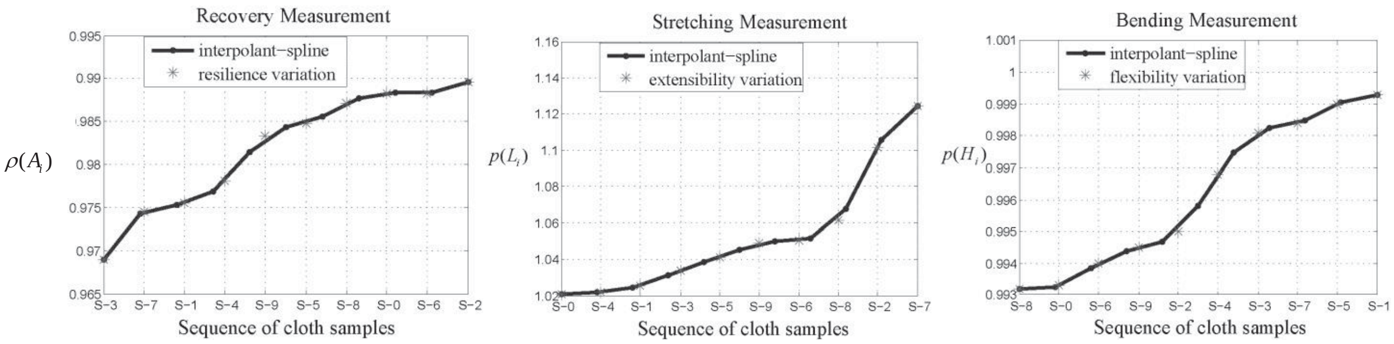
Table 3 shows a database of ten different garment materials. The relative ratio between the three parameters $\partial(r), \partial(s), \partial(b)$ for each cloth sample is learned from the normalized data ($\lambda(A_i), \lambda(L_i), \lambda(H_i)$). The ten materials in our database (see Table 1) are made of different fabric compositions and different woven or knitted patterns. They exhibit distinct anisotropic behaviors, which are representative of a variety of garment materials. While a low numerical error is desirable, it does not always correlate to a perceptual notion of similarity, especially for new configurations. We believe this database to be a useful resource for the graphics community and textile research. The results can be easily included in existing cloth simulators to produce realistic behaviors of many different types of materials in clothing animations, and validate further research on measurement and modeling.

Fig. 3 shows the fitting interpolation curves related to the recovery, stretching, and bending. Using more testing data, the fitting interpolation curves can be obtained according to the appropriate sequence for each cloth sample.

Table 3. The database with the learned parameters for ten different garment materials.

	Sample 0	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
$\lambda(S_i)$	0.9370	0.3156	1.0001	0.0001	0.4418	0.7671	0.9370	0.2671	0.8787	0.6943
$\lambda(L_i)$	0.0001	0.0456	0.7794	0.1240	0.0088	0.2702	0.1976	1.0001	0.3912	0.2886
$\lambda(H_i)$	0.0165	1.0001	0.5903	0.8526	0.8084	0.9509	0.1312	0.8526	0.0001	0.2592

Real fabrics	Material properties			Real fabrics	Material properties		
	$\partial(r)$	$\partial(s)$	$\partial(b)$		$\partial(r)$	$\partial(s)$	$\partial(b)$
0_Red silk	98.26	0.01	1.73	5_Green woolen	38.58	13.59	0.999
1_Blue white dot canvas	23.19	3.35	73.46	6_Blue poplin	74.02	15.61	10.37
2_Blue washed star denim	42.2	32.89	24.91	7_Orange ramie	12.6	47.18	40.22
3-Apricot linen	0.01	12.7	87.29	8_Gray fiber	69.19	30.80	0.01
4_Blue nylon	35.23	0.7	64.06	9_White satin	54.32	22.58	23.1



(a) Recovery (b) Stretching (c) Bending

Fig. 3. The fitting interpolation curves for learned parameters

The parameters from this database can be directly used in a geometrically based cloth simulation and easily used to generate realistic cloth behaviors. Using different parameters can model various types of garment material behaviors. To demonstrate the effectiveness of the learned parameters on each cloth sample (Table 3), we have used these measurement data into the constrained cloth deformation simulators. Fig. 4 shows the simulation results. Shirts made of different garment materials show respective wrinkles and folds when worn by the same human model in our simulation. As shown in Fig. 4(a), the red silk shirt has many small wrinkles and folds, the blue nylon exhibits distinctive appearance (see Fig. 4(b)), while shirts made of blue white dot canvas shown in Fig. 4(c) and blue washed star jean in Fig. 4(d) have less wrinkling details corresponding to their weaving structures.

(a) (b) (c) (d)

Fig. 4. Simulation results for four types of garment materials using the learned parameters in our database.

According to the Figure 4, we can find that different materials show distinctive performances during simulation.

The parameters in our database can be incorporated into the geometrically based cloth simulation and are able to simulate not only the soft material effects of silk and nylon but also the hard materials, including canvas and jean.

5. Conclusions

We have measured the material properties from real-world cloth samples without using expensive or complex devices, and the measured results are directly suitable for application to geometric deformation. Although our experiments show that the proposed optimization framework successfully models anisotropic behaviors of various garment materials, it also has several limitations that need to be addressed in the future. First, we have only measured static parameters. Second, our method only provides an approximation of the material properties of similarity, extensibility and flexibility of the actual cloth samples. In future work, we would like to address the limitations in the current method as described above. And more investigations and measurements are required.

6. Acknowledgement

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